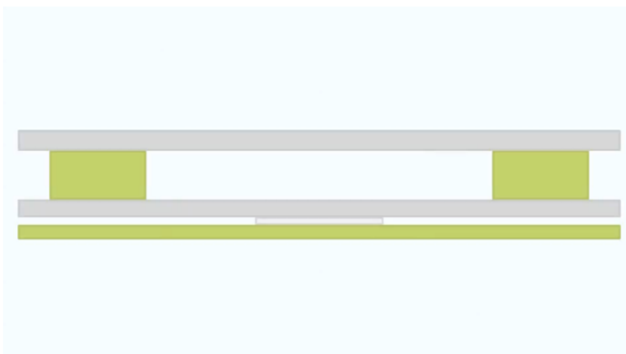
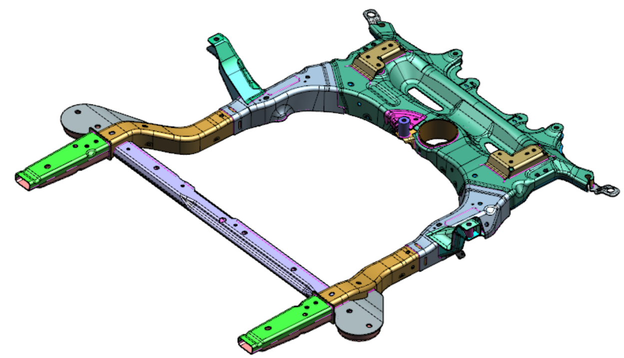
High Strength Steel-Aluminum Components by Vaporizing Foil Actuator Welding





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Presenter: Anupam Vivek

The Ohio State University

June 20, 2018

Project ID: MAT132

Overview

Timeline

- Start Date: October 1st 2016
- End date: September 30th 2020
- Percent complete: 30%

Budget

- Total project funding
  - DOE share: $2,405,625
  - Contractor share: $301,902
- Funding FY 2017: $533,378
  - $475,508 DOE, $57,870 Contractor
- Funding FY 2018: $770,411
  - $688,796 DOE, $81,615 Contractor

Targets and Barriers

- 25% weight reduction on a 2012 mid-size sedan
- Cost premium < $5/pound saved
- Equal or better strength and durability performance
- Predictive modeling and high volume process for mixed-metal joining

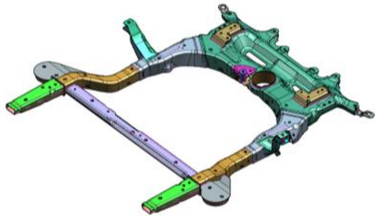
Partners

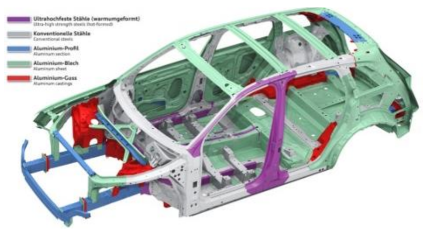
- OSU (Lead)
- Magna
- PNNL
- Coldwater Machine Company
- Ashland
- Arconic
- Hydro (SAPA extrusions)

Relevance/Objectives

- Objective:
  - 20% weight reduction of a current all-steel automotive component from a 2017 mid-size sedan at a cost premium of $3/lb saved by developing a mixed-material joining technology capable of high-volume production
  - The produced component should meet or exceed strength and durability of incumbent component
  - Have a predictive modeling capability for relating process, structure and property of joints
- Project directly addresses the listed barriers and targets

- Impact:
  - ➢ This project accelerates and focuses the development of vaporizing foil actuator for production of an automotive component. At project completion, the technology will be ready for adoption within the research and development groups of Tier 1 and OEM for assembly of any mixed/advanced material bodies

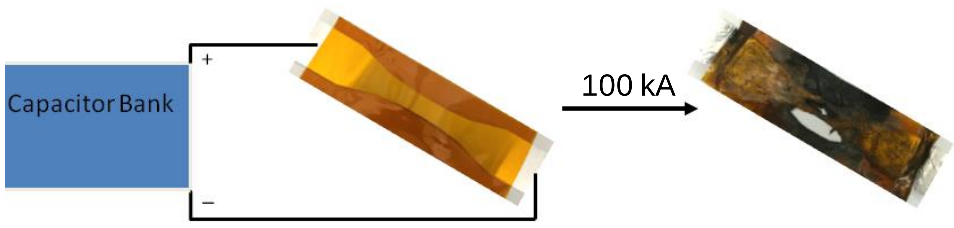


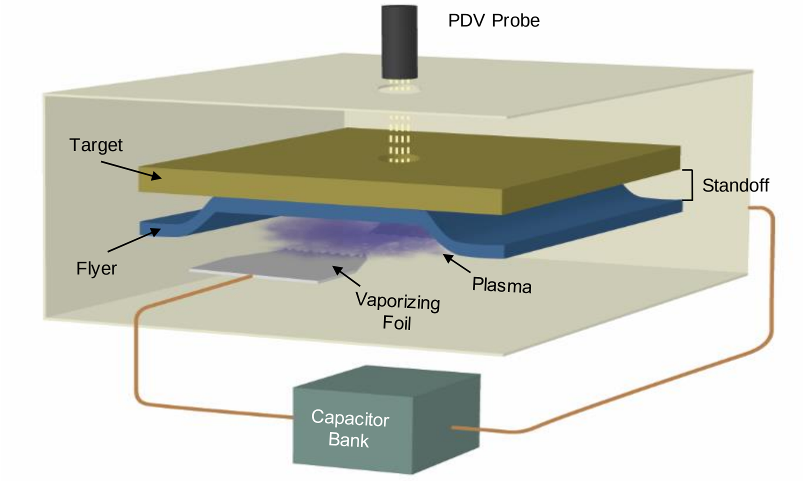


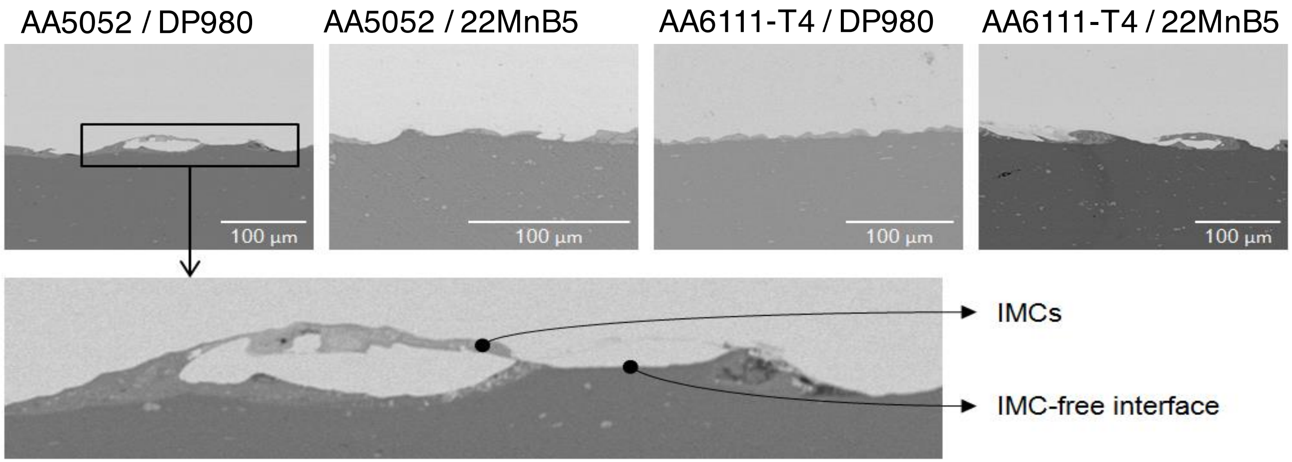
Approach – impact welding

Solid-state impact welding of aluminum to steel

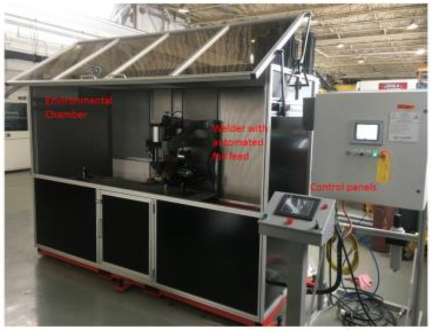
- nominal 500 m/s, 20° impact provides weld.



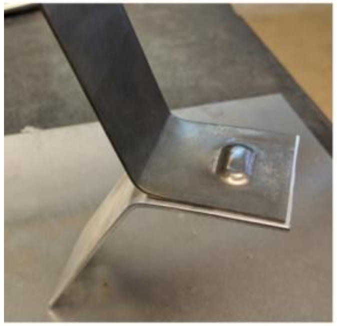




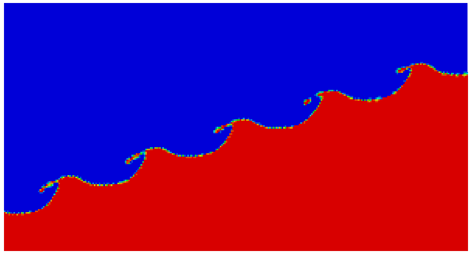
Approach



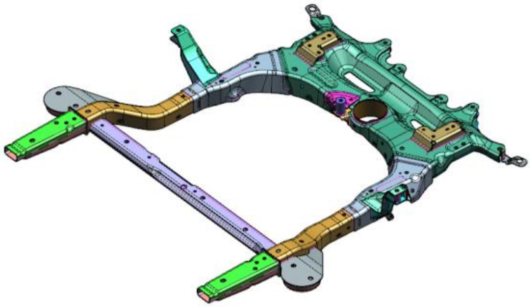
Process & tool development

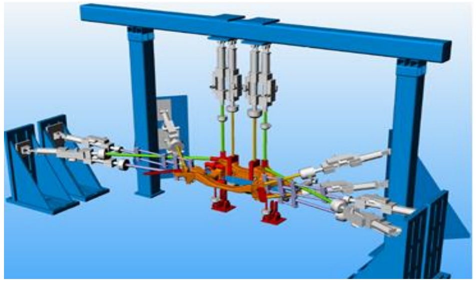


Welding and testing Coupons



Microstructure Characterization and Modeling





Prototype build and durability testing

Approach/Technical Plan

Major tasks	Oct 2016 – Sept 2017	Oct 2017 – Sept 2018	Oct 2018 – Sept 2019	Oct 2019 – Sept 2020
Coupon scale pre-screening	★			
Numerical model development and validation				
Coupon scale testing of down-selected material pairs				
Design for manufacturing of prototype component		★		
Production and testing of prototype components			★	
Design and build of robotic welding system				★

★ **Go/No-Go Milestones**

<u>Budget Period 1: </u>Three material clear down-selection criteria: (i) parent material failure during pry testing (ii)weld strength > 70% of weaker parent material (iii) post-corrosion strength > 80% of pre-corrosion strength

<u>Budget Period 2: </u>Release of prototype design that meets baseline requirement for strength, stiffness and durability

<u>Budget Period 3: </u>Strength and durability of prototype component equal to or better than baseline component

Approach/Milestones

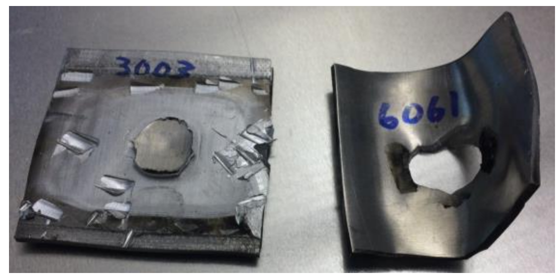
Task No	Task title	Milestone type	Milestone number	Milestone description	Milestone verification process	Anticipated date	Anticipated quarter
1.1	Coupon scale pre-screening		1.1.1	6 material systems selected for preliminary investigation	Benchmarking	M3	1
			1.1.2	Pedestal system integration complete	Demonstration	M6	2
			1.1.3	Weld interface with IMC thickness <2μm obtained	SEM	M9	3
		Go/No-Go	1.1.4	Three material systems clear the threshold for further testing (parent material failure during testing)	Mechanical testing	M12	4
1.2	Modeling		1.2.1	The range for appropriate welding angles recommended	Comparison to experiment	M6	3
2.1	Further coupon test		2.1.1	High cycle fatigue limits are >30% of static yield strength of the coupons	ASTM tests	M18	6
2.2	Model validation		2.2.1	Predicted wavelength and amplitude within 80% of experiments	SEM	M21	7
			2.2.2	Predicted strength within 90% of experiments	Comparison to experiment	M24	8
2.3	Design of prototype		2.3.1	Math data and load profile for baseline cradle design ported into the new design	Data supplied by OEM and used by Magna	M15	5
		Go/No-Go	2.3.2	Release of prototype design and its CAE performance	Compared to baseline	M24	8
3.1	Production and testing of prototype		3.1.1	25 sets of subcomponents produced	Actual production	M27	9
			3.1.2	Prototype assembly fixtures built	Demonstration	M30	10
		Go/No-Go	3.1.3	Ten prototypes assembled	Actual production	M32	11
			3.1.4	Static and dynamic loads exceed all-steel design	Mechanical testing	M34	12
			3.1.5	CAE predictions within 90% of the physical tests	Comparison to prototype tests	M35	12
3.2	Robotic VFAW		3.2.1	Design of robotic VFAW system released	Design shared with Magna	M36	12

Complete In Progress Not started

Technical Accomplishment:
Screened 8 material pairs

- **5 pairs had welds stronger than base metal when pry tested**

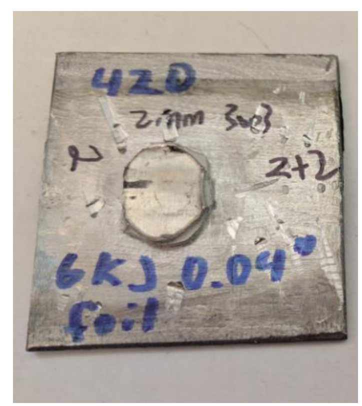
Material Combination	Pry testing result (flyer thickness)
AA6061-HSLA 340	Parent (3.175mm)
AA5754-HSLA 340	Interface (3.3mm)
Aural 2- HSLA 340	Parent (3.3mm)
A356- HSLA 340	Parent (6mm)
6061-HSLA 420	Interface (3.3mm)/parent (2mm)
5754- HSLA 420	Interface (3.3mm)
Aural2- HSLA 420	Parent (3.3mm)
A356- HSLA 420	Interface (6mm)



HSLA 340-AA 6061 (3.175mm)


HSLA 340-Aural 2 (3.3mm)


HSLA 340-A356 (6mm)



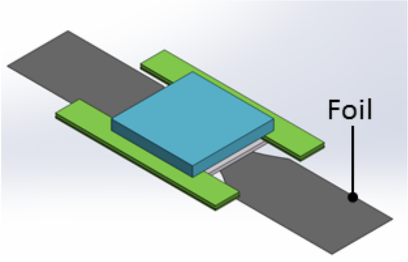
HSLA 420-AA6061 (3.175mm)

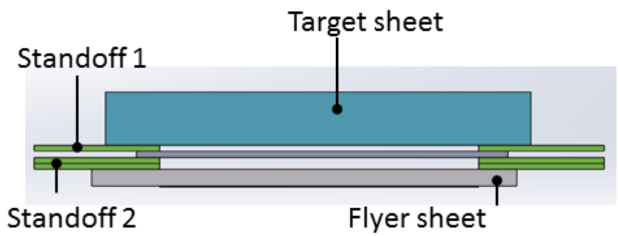

HSLA 420-Aural 2 (3.3mm)

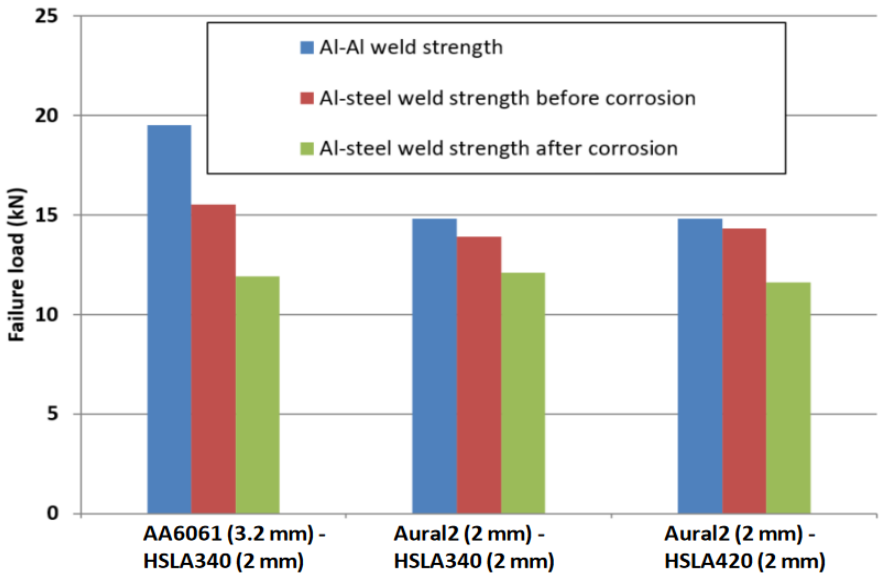
Technical Accomplishment:

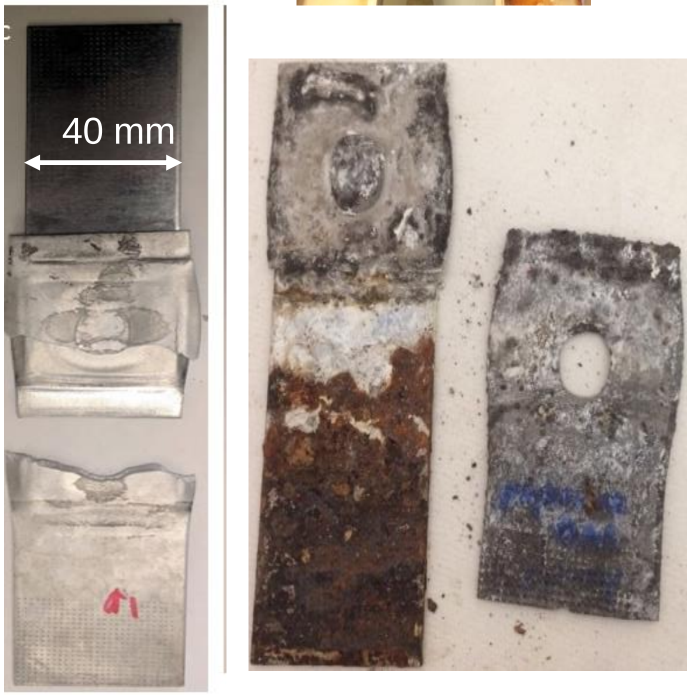
Instrumented testing of pre and post-corrosion samples

- >70% joint efficiency
- >80% strength retention after corrosion
- Met Go/No-go criterion for Budget Period 1







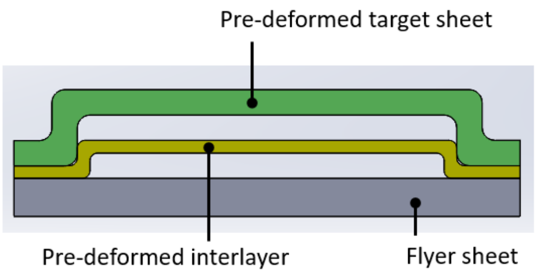


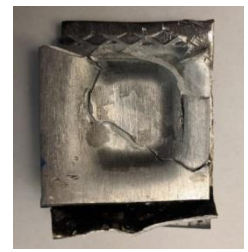
HSLA 340-Aural 2 (3.3mm)

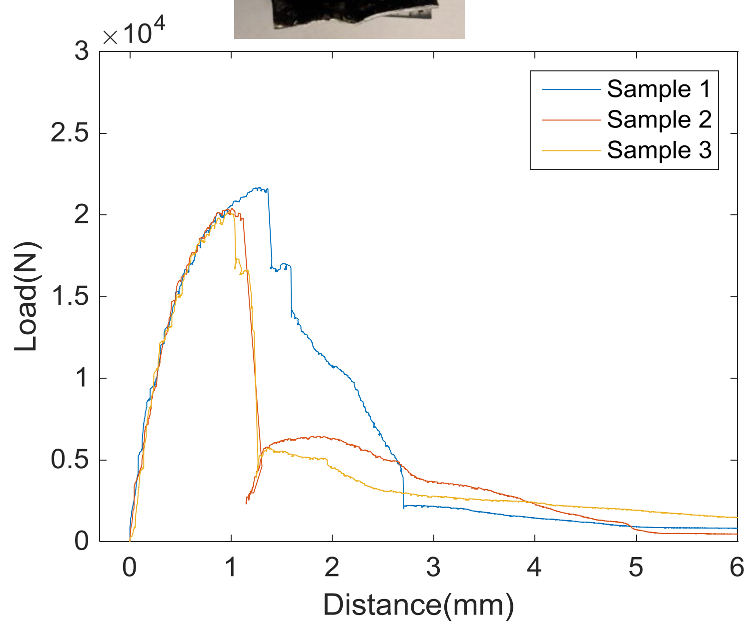
Technical Accomplishment:

Instrumented testing of selected pairs with pre-formed configuration

- **Shear failure load > 20kN obtained**
- **Weld strength matches interlayer material (AA3003)**





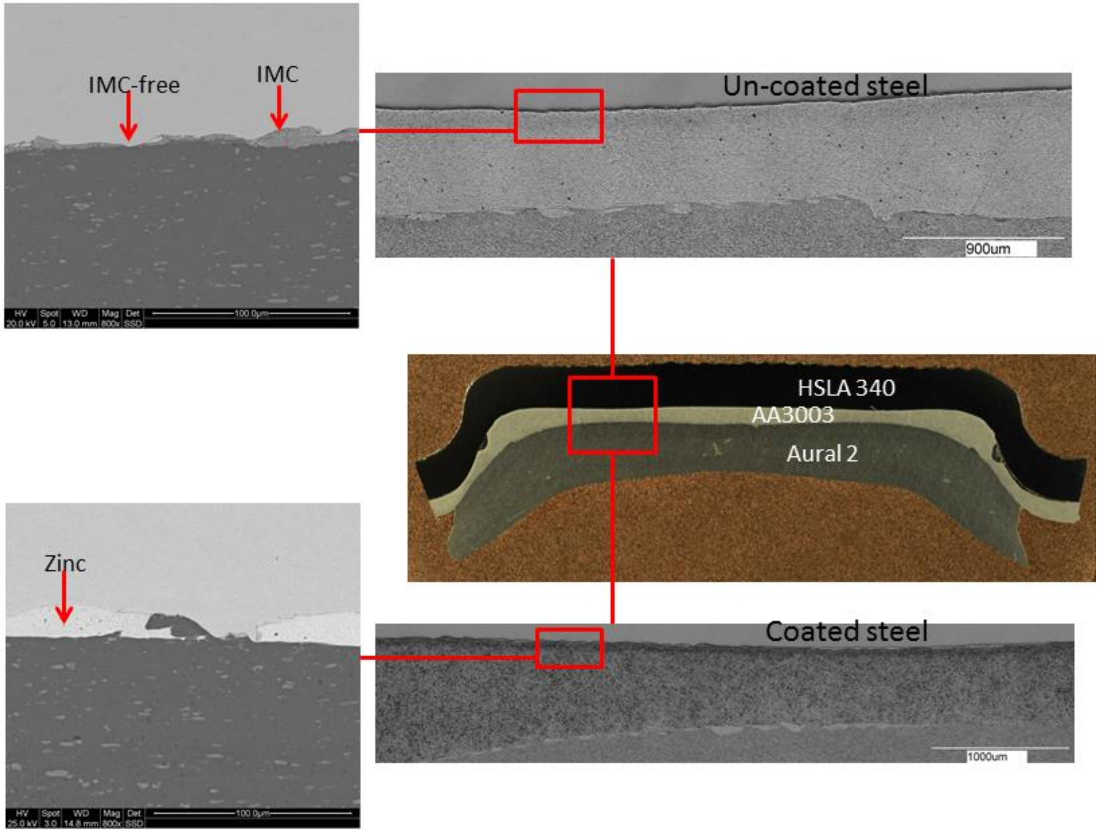


HSLA 340-Aural 2 (3.3mm)

Technical Accomplishment:

Weld Characterization

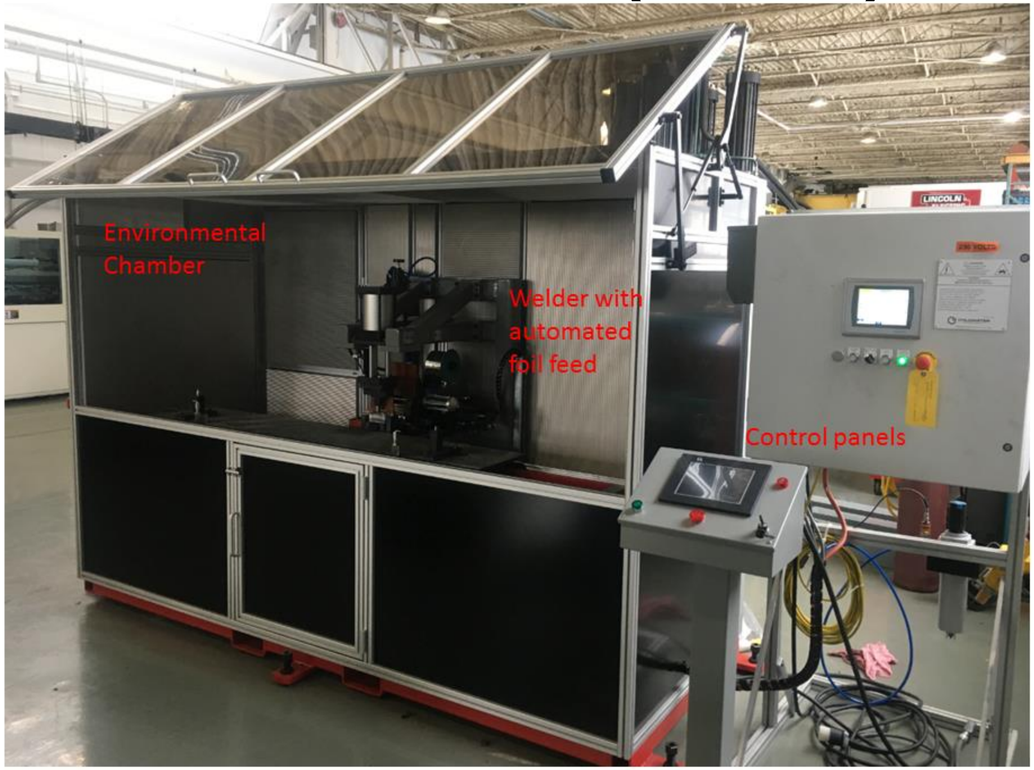
- Interfaces with intermittent intermetallic compounds (IMCs) formed
- Welded to un-coated as well as coated steels

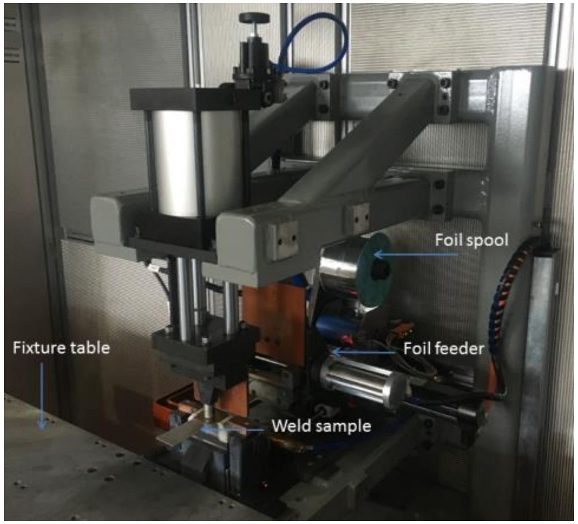


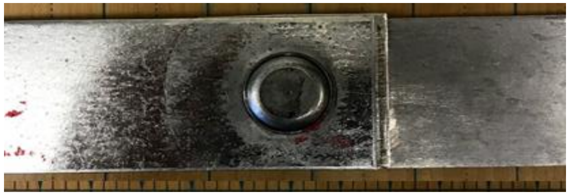
Technical Accomplishment:

Development of Pedestal-Style Welder

- **Pedestal welder built and tested**
- **Automated foil feed**
- **HSLA 340-Aural 2 (3.3mmt) welds with input energy=4kJ**



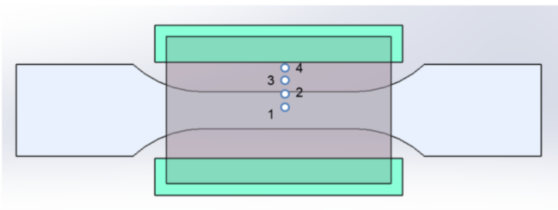


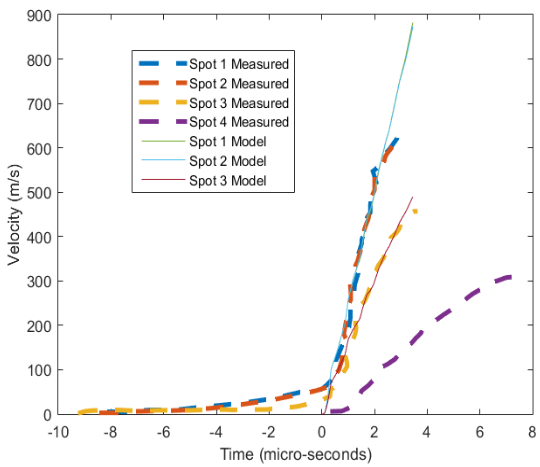


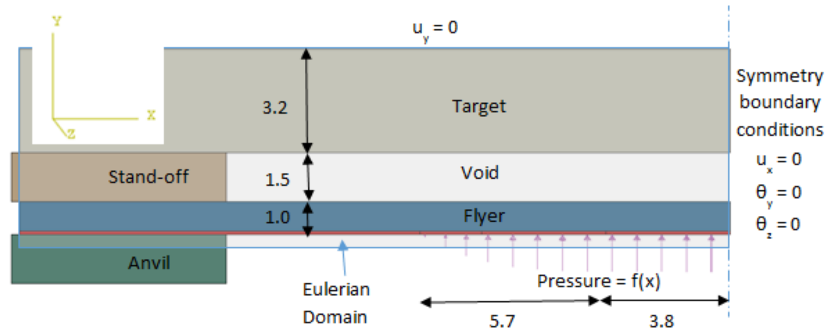
HSLA 340-Aural 2 (3.3mmt) weld

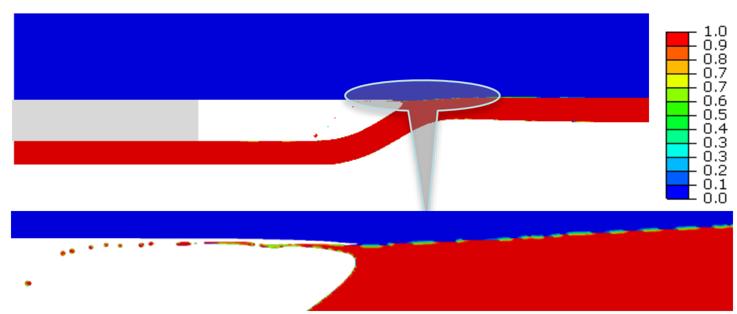
Technical Accomplishment:
Validation of Process-Structure Numerical Model

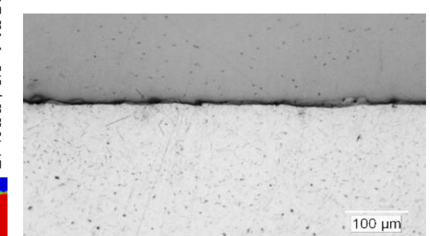
- Model validated on aluminum-steel: jetting and interface morphology





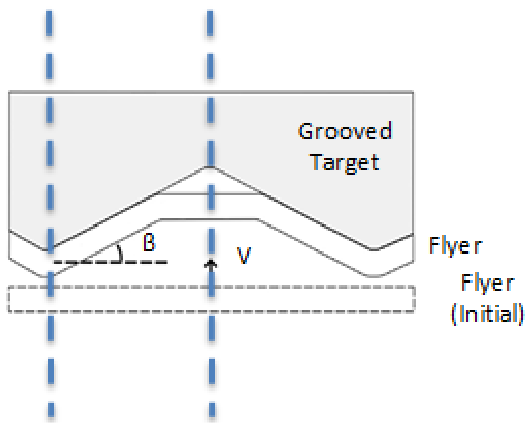


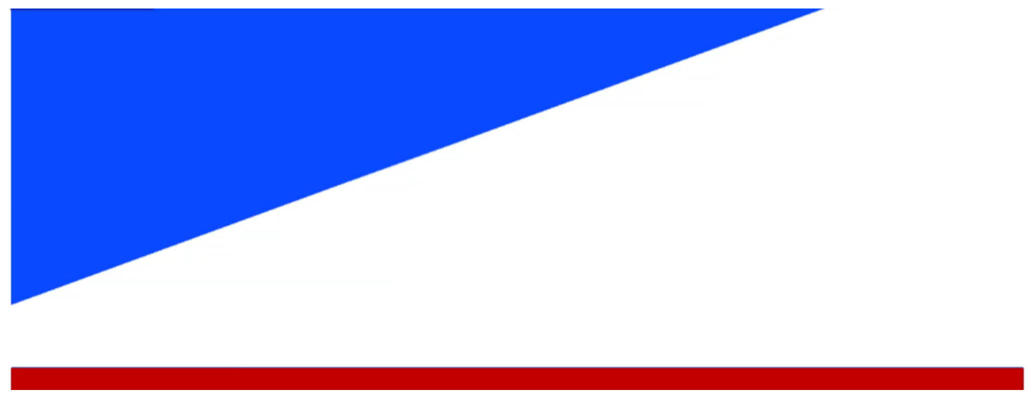


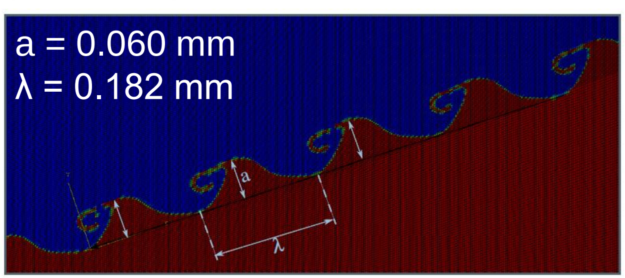


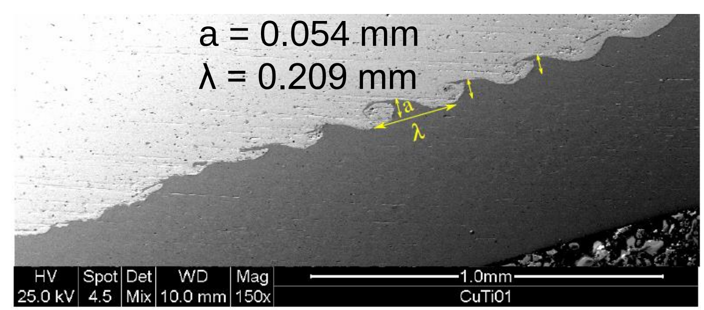
Technical Accomplishment:
Validation of Process-Structure Numerical Model

- Model validated on Copper-Titanium system: amplitude and wavelength of interfacial waves









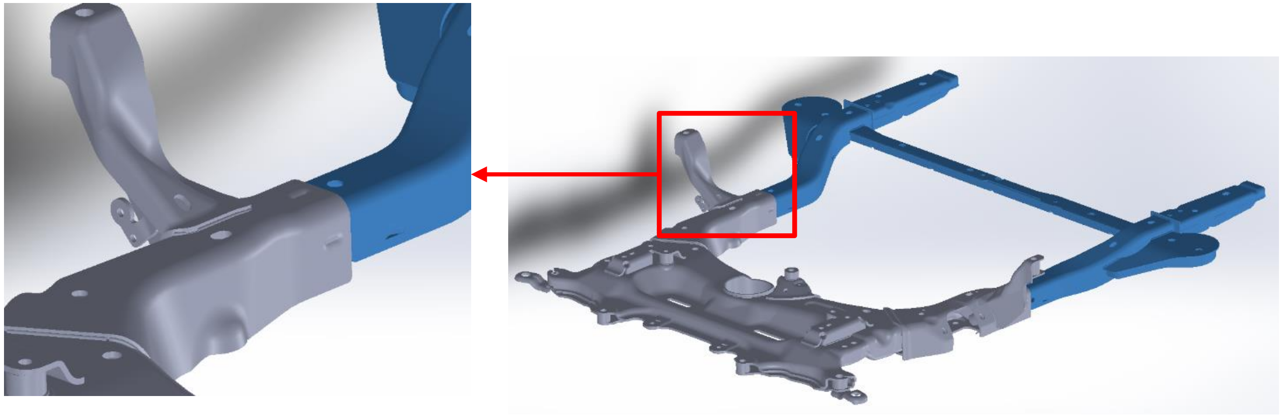
Model validated over many collision speeds and angles; here β=20° and V=770m/s

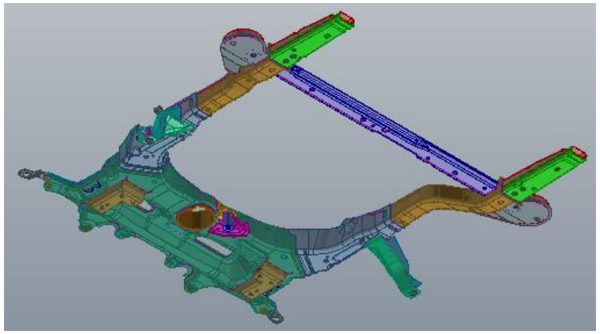
Vivek et al, *Materials Processing Technology,* 214, pp. 1583-1589, 2014

Technical Accomplishment:
Selection of Prototype Component

- **2016 Chevrolet Cruze**
- **Global/US Volume: 600,000/250,000 per year**
- **50.7 lbs (all-steel) -> 40.6 lbs (target hybrid)**
- **With aluminum front end, estimated weight: 41 lbs**
- **Design based on AA5754 (4mmt) stampings joined to HSLA 340 steel**

Optical Scan

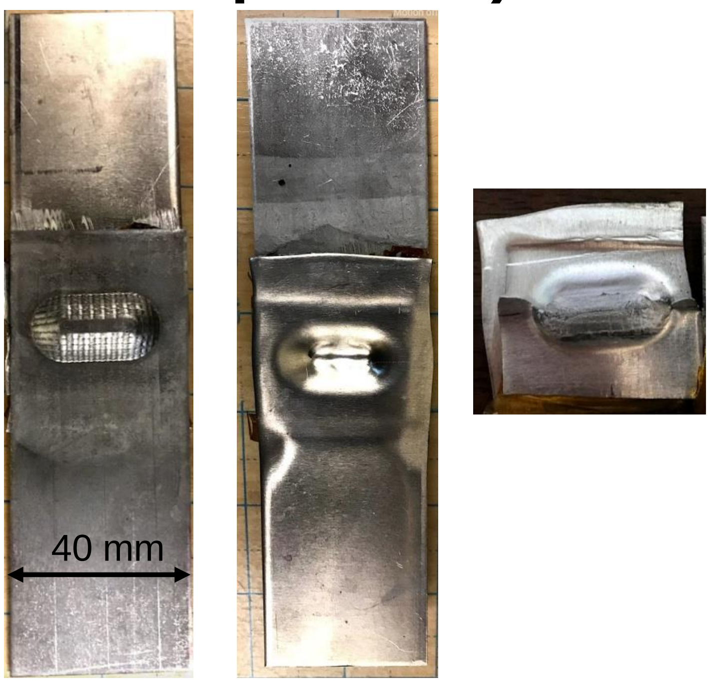




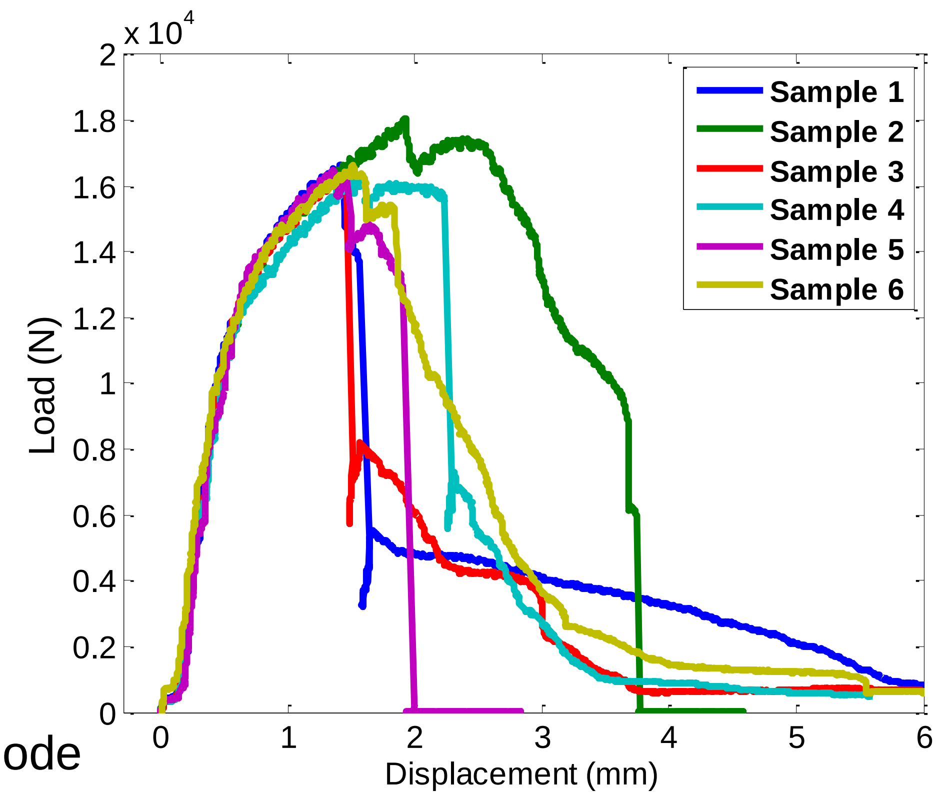
Concept welded hybrid structure, detailed design being developed.

Technical Accomplishment:
Welding stamping grade aluminum to steel

- **Lap shear strength of HSLA 340-AA5754 (3.3mmt) exceeds 15kN (meets AWS spec D8.2M:2017 for Al-Al spot weld)**



Extended spot welds and failure mode



Responses to Previous Year Reviewers' Comments

- This project was not reviewed last year

Collaboration and Coordination

- **OSU's Impulse Manufacturing Lab, Fontana Corrosion Center, CDME:** Facilities and expertise for impact welding, process development, standard corrosion testing at coupon and subcomponent level in addition to program management
- **Magna (Sub):** CAD, CAE, prototype build and testing
- **Coldwater Machine Company (Sub):** equipment builder and system integrator
- **PNNL:** Numerical simulation of impact welding process, interfacial wavy pattern and jetting, and mechanical performance of the welded coupons
- **Ashland:** Supplies structural adhesives for galvanic corrosion protection. Also provides in-house testing
- **Arconic:** Supplies 5xxx and 6xxx sheets for screening tests and prototype build
- **Hydro:** Supplies 6xxx and 7xxx grade aluminum extrusions for possible chassis and body side applications

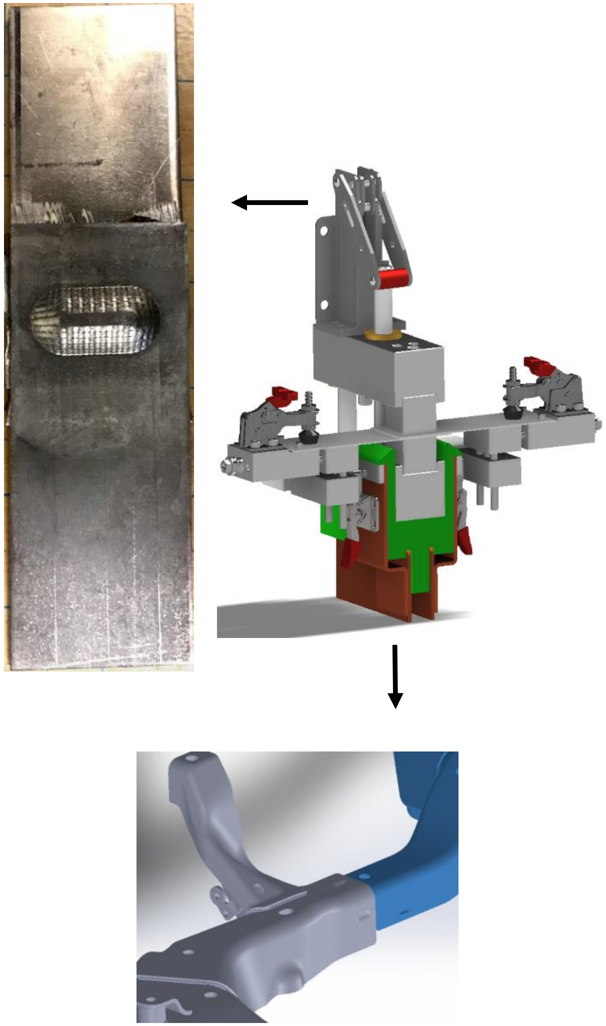
Remaining Challenges and Barriers

- Experimental
  - Weld-to-weld reproducibility
  - Prototype scale assembly
  - Weld cycle time
  - Weld+adhesive

- Computational
  - Weld characterization data: mechanical and microstructural
  - Reliable high strain-rate constitutive properties for automotive materials
  - Development of load cases for prototype model

Proposed Future Research

- FY 2018: Welding of 4mmt AA5754 to HSLA 340 steel
  - Quasi-static mechanical testing in x, y and z directions (>6 samples each)
  - Fatigue testing to reveal S-n curves in x and y directions (5 loads x 6 samples)
  - Post-corrosion quasi-static testing of samples with and without adhesives (>6 samples each)
  - All welds to be created with a welding system, which has precise alignment fixtures
- FY 2018: Design of the prototype component that meets the performance of incumbent design
- FY 2018: Structure property modeling of 3-layer welds
- FY 2018-19: Adaptation of coupon welding system to accommodate prototype component welding
- FY 2019-20: Design and build of robotic welding head



Summary

- Vaporizing Foil Actuator Welding (VFAW) has been shown to successfully weld casting, stamping and extruded grade aluminum alloys in thicknesses (3.3mmt) relevant to sub-frame structures. In related work, greater than 6mmt aluminum has been welded.
- Automation of foil feed, a major barrier for mass adaptation of the technology, was demonstrated. The equipment development work in FY 2018 will focus on improving weld-to-weld reproducibility through precise relative positioning of foils and workpieces.
- A validated process-structure model is now available for simulating impact welding processes. It does require a larger data base of material constitutive properties.
- A baseline prototype component has been selected and is being redesigned for manufacturing of an aluminum-steel structure that will be 20% lighter. The prototype design will be released for production in October 2018
- FY 2018 coupon-scale work will focus on generating statistically viable data set for weld strength and durability

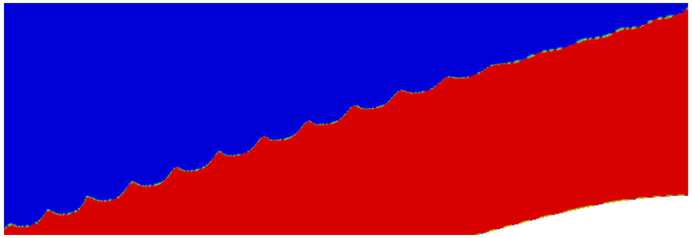
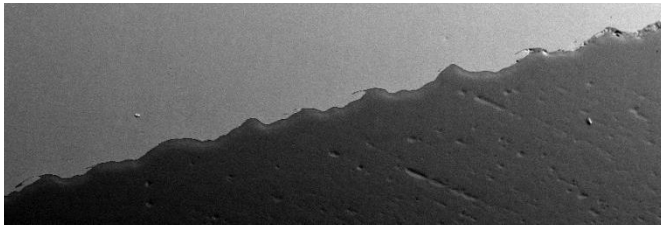
Technical Back-Up Slides

Effect of Impact Velocity

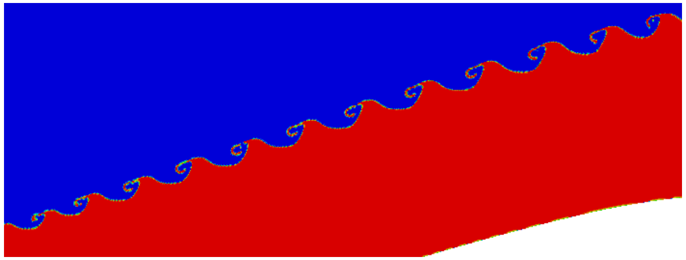
Impact angle, β =20°

Simulation | **Experiment**

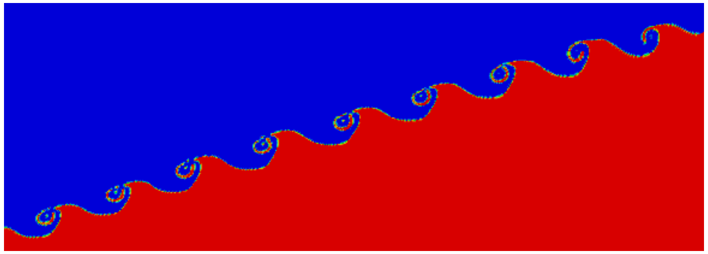
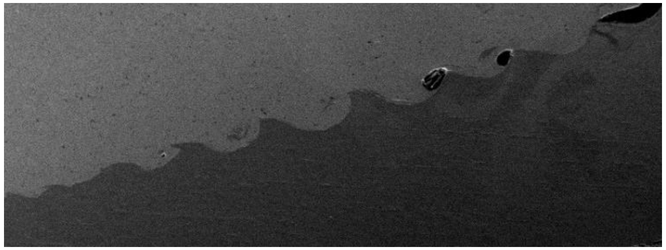
585 m/s

770 m/s




860 m/s

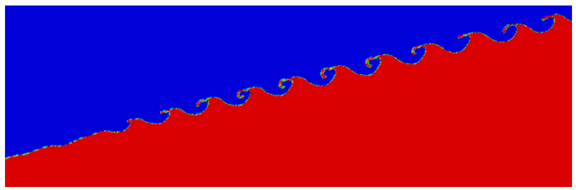



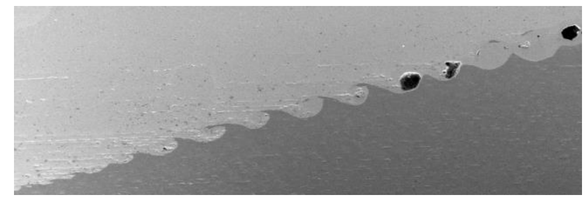
Effect of Impact Angle

Impact Velocity, V_p = 770 m/s

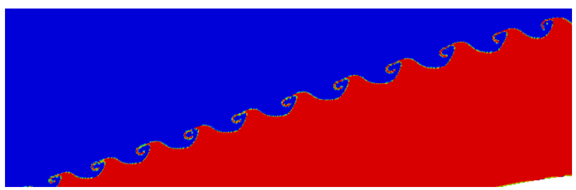
Simulation | **Experiment**

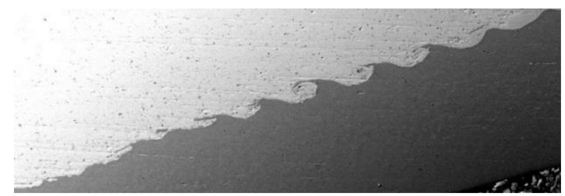
β = 16°



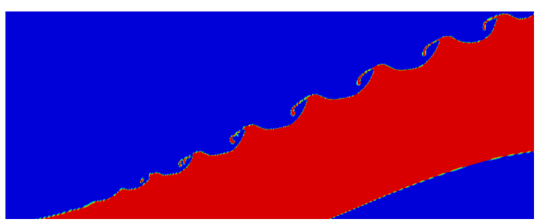


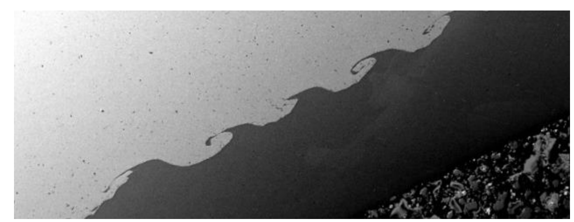
β = 20°





β = 28°

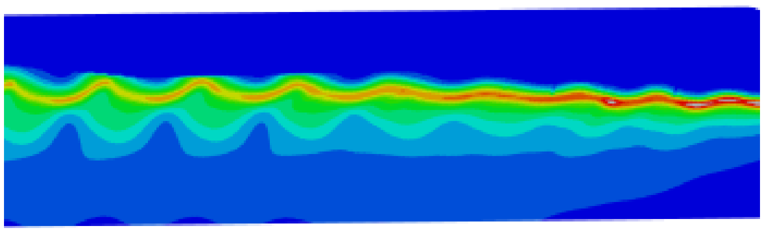


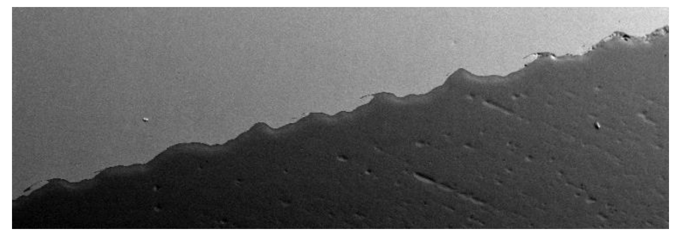


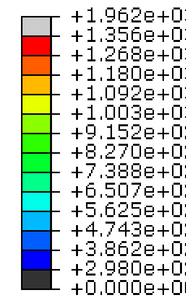
Temperature Predictions

Impact angle, β =20°

585 m/s

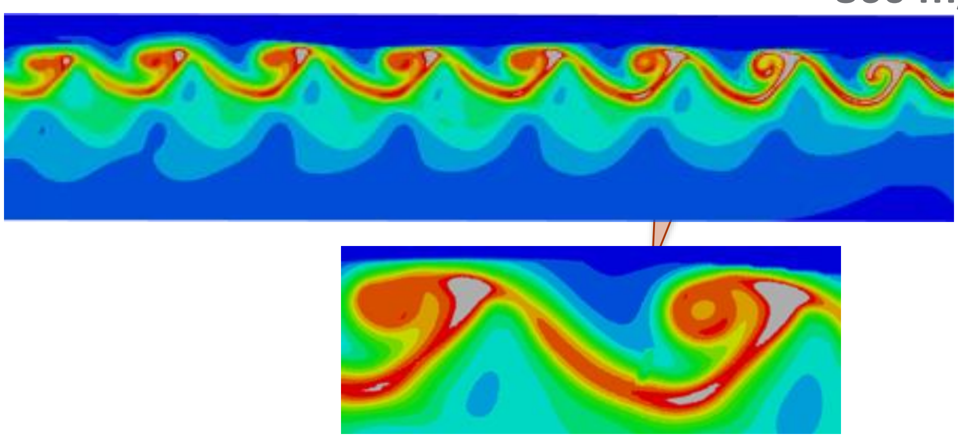


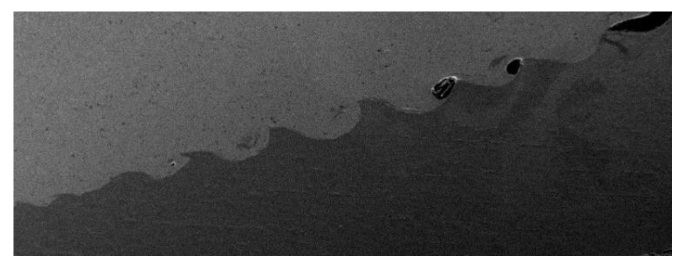




860 m/s

Grey color in the contour represents temperature values above melting point of Cu





- Temperature predictions can help in understanding composition at the interface